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TRANSPORT AIRCRAFT COCKPIT STANDARDIZATION (FEDERAL AVIATION REGULATIONS PART 25)

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16. Abstract

The present status of transport aircraft cockpit standardization was evaluated by examination of regulations and other design practice documents and by interviews with airline pilots and engineers. Flight critical areas most in need of increased standardization were identified as (1) primary flight guidance instrumentation and (2) pilot input keyboards.

Additional areas proposed for further industry consultation, possibly leading to further standardization at a future date, include flap, slat, and leading-edge device control and display systems; indicated airspeed (IAS)-Mach indicators; powerplant instrumentation; and electric and hydraulic power diagrams, displays, and controls.

The continued use of a mixed metric and English unit measurement plan in both United States and foreign manufactured aircraft is noted, and the incidence of pilot dual qualifications and the need for criteria for digital system software certification are also discussed.

The present status of transport aircraft cockpit standardization was assessed to determine whether or not there is a need for actions by the Federal Aviation Administration or the industry.

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METRIC CONVERSION FACTORS

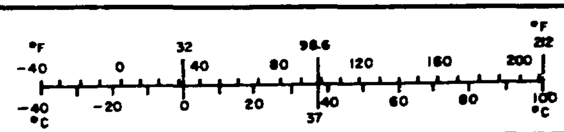
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

This study is one part of the recently developed Federal Aviation Administration (FAA) engineering and development program called Aircrew Performance Enhancement and Error Reduction APEER). The specific project objectives were (1) to assess the present status of transport aircraft cockpit standardization, including present FAA and industry regulations and other standardization efforts, and the aircraft fleet standardization that has been accomplished as a result and (2) to make recommendations for appropriate future FAA actions that would increase safety through advances in cockpit standardization. The project was conducted in the context of other ongoing and more time-critical studies of related topics such as transport aircraft crew complement (the workload evaluation issues related to two-pilot flight decks versus those designed for three crew members) and advanced instrumentation tests and evaluations. For this reason, the present treatment of cockpit standardization is general and global rather than addressed to specific points currently at issue such as flight instrument symbology, the use of colors on cathode-ray tube (CRT) displays, and the best formats for digital input and readout devices. Further, since there are no published and widely accepted handbook guidelines for many human engineering applications in cockpit design, the viewpoints expressed herein should be taken as the best opinions of the author, devoid of the sanction of general professional review and approval.

BACKGROUND.

DEFINITION OF COCKPIT STANDARDIZATION. Before discussing what has been done in the past and what may be attempted in the future to bring about the widely acknowledged, desirable goal of increased cockpit (or aircraft flight deck) standardization, it is necessary to define what is meant by this term. In the present context, standardization means, (1) those aspects of similarity of appearance—visual, aural, tactile, and kinesthetic coding—that are detectable to a pilot, (2) general congruence of configuration—arrangement of elements and their placement in relation to other displays and controls, and (3) uniformity of operating principle—the function indicated by a display or the operation accomplished by a control that is the same in meaning and application. In short, the meaning given to standardization is a functional one. Neither elements nor groupings need be identical to accomplish such functional standardization, but all elements must be readily identifiable to avoid confusion. The meaning of critical indications and perceived forces must be sufficiently similar to those experienced on alternately designed flight decks so that identification of type, discrimination of important changes in information, and determination of the relationship of interacting elements are readily transferable from one aircraft to another.

An example of the first class of functional standardization, herein called similarity of coding, may be cited in the use of color on visual displays. The standard and approved use of the color green is to indicate satisfactory conditions, operation in the normal limits, and go. Red, in contrast, is the selected color for warning, operation in excess of normal limits, and stop. It will be noted that the common use of a red lamp to show power-on, unit-activated, or switch-on tends to be a confusing, overlapping meaning. In this sense it would be said to be nonstandard.

An example of the second broad meaning of standardization, layout similarity, is found in the "basic T" instrument panel. In the T, the best indication of altitude is immediately to the right, and the best indication of speed is immediately to the left of the primary attitude indicator. Direction information is displayed below the altitude indicator. Partial violation of the principle of configuration standardization may be alleged when the primary altimeter is displaced one instrument space to the right of the primary attitude instrument to allow insertion of a radar altimeter, which is used primarily or exclusively in final approach. Alternatively, violation of layout similarity may be asserted if the internal arrangement of elements in the flight director attitude indicator does not parallel the basic T; e.g., if the height, above and below glide slope, is not placed to the right (the side on which the altitude indicator is placed) and the fast-slow scale is not placed to the left (the side on which airspeed indications are read).

An example of the final meaning of standardization, the category of uniformity of operating principle, may be found in the usual adherence to human engineering handbook guidelines with respect to switch positions and directions of magnitude controls. According to these guidelines, a toggle switch is "up" for ON or GO and "down" for OFF or BRAKES SET. Similarly, an electrical or power application control is rotated clockwise to increase, and a liquid flow control is rotated counterclockwise to increase. While the "faucet" principle is accepted for fluid flows ranging from water to hydraulic materials, violations of standardization or ambiguous applications may occur with systems that are neither obviously electrical/power nor fluid in nature. For example, some applications increase temperature by increasing the power or fan pressure and may follow the clockwise stereotype, while other applications increase temperature by reducing the power or closing off the cooling flow. In the second case, temperature is sometimes increased by turning counterclockwise. Thus with heat-adding and heat-dissipating systems, there may be a conflict produced by following two different stereotypes—that of added power equals clockwise movement (whether the purpose is to add or remove heat) and that of added flow equals counterclockwise movement (whether the flowing media is heating or cooling). While violations of handbook stereotypes are rare in transport aircraft, conflicts may arise in borderline cases; the most obvious example being the toggle switches placed on an overhead panel. Such a panel normally slopes up to the rear. Hence, one airline may elect the "up" position for ON, despite the fact that it means moving the switch handle slightly to the rear, while another airline may require all such toggles to have "down" represent the ON position since down is toward the front or GO position. (In the L-1101, this conflict was avoided by eliminating all toggle switches over the pilots' heads. The corollary advantage was the avoidance of projections that could impact their heads. The toggle switches were replaced with recessed pushbutton switches, for which the guidebook stereotype is "in" for ON.)

The preceding discussion of the meaning of the term standardization is believed to be in accord with the best opinion of the manufacturer and airline representatives who were interrogated in the course of this study. Each aircraft manufacturer expressed interest in designing future flight decks in conformance with (1) existing standards and federal regulations that have either the sanction of law or the strength of longstanding usage and also (2) the best engineering practice currently developed within the industry and having a purely voluntary incentive. At the same time, manufacturers acknowledge a basic conflict between the goal of single-model standardization and industry-wide standardization. Thus, a given manufacturer would prefer, for economic as well as training and safety advantages, to arrange all his flight decks in the same pattern and insofar as possible, equip all of them with the same units of hardware, procedural elements, and digital software systems. This cannot be done, however, without changing the flight decks of long production-run aircraft that were designed before the improved systems of today were available. The most extreme example of a forced compromise of this sort is noted in the continued use of three-pointer altimeters in current-production transport category aircraft. In a year when many Beech 99's were produced with all-digital, integral-lighted altimeters, it seems incredible that a turbojet transport, seating 175 passengers, was also produced with an obsolete and error-implicated three-pointer altimeter. The contrasting goals of type versus industry standardization hold the explanation.

RELATION OF STANDARDIZATION TO SAFETY. As the first step in starting this project, all turbojet transport accidents involving fatalities or destruction of the aircraft (hull-loss) occurring since 1958 were studied by reading individual accident reports and accident class analyses published by domestic and foreign authorities and specialists in accident analysis. It was found that instances of attribution of cause to nonstandardization were rare. When such instances occurred, it was generally in the form of speculation as to possible reasons why the pilot failed to correct the situation. For example, the B-727 that crashed into the ocean off Los Angeles in 1969 was said to have a variant electrical panel, and it is possible that the second officer, in attempting to turn off galley electrical power subsequent to a generator loss, erroneously turned off the battery power to essential flight instruments, thereby contributing to spatial disorientation by the captain. After such a crash it is not feasible to prove exactly what was done, what was thought, or even what was said, since even the voice recorder went dead when essential battery power was interrupted. Recovery of essential power seconds before the crash into the sea made it likely that an inadvertent switch actuation had occurred. The proximity of an unguarded main battery-buss switch to the galley power switches made it thinkable that the error might have occurred in an attempt to carry out the standard checklist for unburdening a remaining generator. Since this speculation could never be proved, it did not enter into the primary finding of cause. It seems likely that the same reasoning has prevented investigating authorities from making hypotheses about pilot-error accidents in many other cases.

To some extent, this difficulty of placing the blame for an accident squarely on flight deck provisions that allow errors to occur extends to other types of bad human engineering. A notable example may be found in the case of the unguarded lift-spoiler system on one of the early four-engine turbojets. Several accidents occurred in which lift apparently was lost due to in-flight deployment of spoilers, but it was not until a particularly dramatic voice recording of the captain saying "no, no" and the first officer saying he was "sorry" that a guard was installed. The guard prevents an action which could be taken with lethal results in one aircraft although it was common practice in other aircraft. These examples serve to illustrate the difficulty of showing that accidents are caused by non-standardization and other forms of bad human engineering, the causal factor category sometimes referred to as "design induced error." In addition, two considerations make it unlikely that a definite cost can be assigned to nonstandardization. The first is that there is a very long history of interest in flight deck design, and the modern designs have evolved through a gradual process of adaptation that ensures incorporation of many lessons learned through usage. The second is that the importance of differences is explicitly recognized in regulations; training in these differences is required, and there is great emphasis on type ratings and type currency. Human beings are able to cope with complex and varied arrangements up to a point. There are, nonetheless, several general concepts relating safety to flight deck design that should be stated.

The relationship between aircraft standardization and flight safety should be clearly distinguished from any implication that aircraft certificated under present rules are deficient in safety or that increased standardization is itself a panacea. Instead, the present emphasis can be understood in terms of two axioms about accidents. First, it is widely agreed that most accidents result from a combination of unfortunate circumstances rather than from a single cause such as pilot error, aircraft defect, or environmental stress. Most often, the fully illuminated accident will be found to be the final effect of a pilot-aircraft-environment causal chain. Recognition of this causal chain implies, however, that the likelihood of the typical accident can be reduced by an improvement at any part of the sequence. Increased pilot proficiency, greater safety margins in the aircraft, or less stressful weather might, in a given case, break the chain. Second, invertigation does not always or even usually yield the full description of the causal chain. It is impossible to state the exact percentage of accidents which are attributable to pilot factors, aircraft factors, or environment and, hence, to determine the potential extent of safety improvement to be developed. Often, the possible cues to causation are destroyed as a result of the accident. Even full preservation of the damaged aircraft and pilot survival does not ensure that (1) the specific sequence of cause and effect, (2) the cause resulting from that effect and consequent second level effect, and (3) the final culmination can be reconstructed. Under stress, an otherwise well-practiced response may be replaced with an action learned earlier and practiced extensively in a different aircraft. The pilot may forget the new response and fall back on an old habit. After the fact, it might be difficult to remember why the wrong control was selected or why inappropriate action was taken. In the general aviation area, where the larger number of operations and the larger number of incidents provide a larger sample of events, it is well-recognized that nonstandard placement of retractable gear handles is related to inadvertent gear retraction accidents. Even in this case, however, most pilots cannot remember what caused the confusion; e.g., engaging the gear device instead of the flap handle. It is safe to say, then, that flight deck design is important to safety and that standardization is an important aspect of design even without a documented plethora of accidents attributed to these causes. Similarly, we know that severe weather is related to causation of some accidents, but it is seldom possible to detail the exact aerodynamic forces that impinged on a particular aircraft. Aspects of the man-machine interface in the cockpit are acknowledged to be related to ease of operation under stress. It is only reasonable to translate this into a safety relationship despite our inability to place quantitative values on the relationship.

These principles of accident causation and description suggest that increased cockpit standardization can be justified if it can be demonstrated that the lack of standardization, or the allowability of designs that are known to be inferior, is a possible contributing cause of accidents. It is not neccessary to prove that the particular instance of lack of standardization was the sole or even the culminating cause of an accident. Total system safety would be advanced if increased cockpit standardization made a reduction in the probability that some level of pilot factor would interact with aircraft factors to sustain an accident causal chain. Similarly, it will never be established in exact statistics that any given number of injuries would have been prevented if all cockpits had been equipped with some particular protective feature. This is because in the real world it is not sensible to conduct a comparative experiment with real pilots. We do not equip half of the fleet with a protective feature, deny that feature to the other half of the fleet, and count the injuries. Instead, protective features such as body restraints are introduced in variable forms over a period of time. We may be able to infer from individual accident analyses, and from controlled experiments with synthetic accidents, that a substantial safety advantage is conferred by use of the protective system in question, but we cannot actually count lives saved or injuries prevented. For these reasons postulation that safety requires a specific standardization action should never be an absolute and numerical statement. Knowledge accrued from experience with different usages in aircraft other than those covered by the regulations, other standardization guideline knowledge following from various types of surveys and experiments that do not exactly duplicate the aircraft environment, and assumptions based on the logic of causal sequences that are produced by accident analysis should all play a part. Underlying this study, then, is recognition that the cause influencing the pilot leads to an effect, that this effect may become a cause in the pilot-aircraft interaction, and that many accidents result from a further linkage of that interaction with environmental stress. Since this is the true genesis of most accidents, there are several possible approaches to increased flight safety. Very important among these approaches will always be the standards of pilot training and proficiency. But the fact that better trained and more current pilots would be expected to have fewer accidents is not a refutation of the logic factor of seeking improvement in the aircraft.

This study concerns an attempt to break the pilot-aircraft-environment causal chain at the point that the pilot effect is active in the cockpit. Examination of the stages of pilot-aircraft interaction in the cockpit may suggest a rational approach. Figure 1 is intended to illustrate the loop of pilot information processing. It is reprinted from a related study of Federal Aviation Regulations (FAR), Part 23, Aircraft Standardization, FAA/RD-77/192.

The pilot in the cockpit is viewed, then, as engaged in perception of information about his aircraft state and dynamics and information about the environment. He senses and detects significant information which may include, of course, a danger signal. This detection of significant information may be impeded if an important signal is not in the pilot's field of view, is blocked, or is not discriminated from the noise context because it is too weak in signal strength or is unclear. The term "comprehension" is meant to suggest the recognition and interpretation of the importance of incoming information. A signal might be perceived, for example, but not be recognized as having an important bearing on some aspect of the situation that is, in fact, critical. The complexity of displays and the magnitude of the workload imposed by concomitant cockpit tasks may influence the completeness of comprehension. Decision is the information-processing phase in which the pilot selects, from a repertory of alternatives, the particular action that is appropriate. A danger signal may be perceived and its importance may be comprehended, but the correct action may not be elected. Finally, a failure may occur when the pilot implements the selected action.

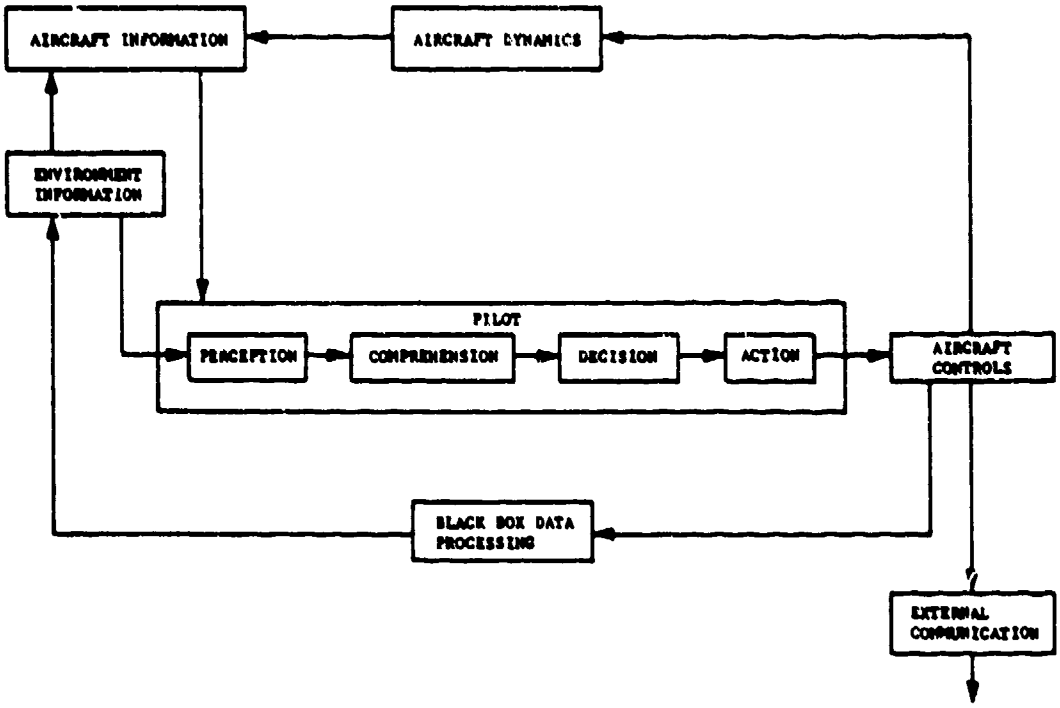


FIGURE 1. THE PILOT-AIRCRAFT-ENVIRONMENT INFORMATION FLOW

The physical action itself may be poorly coordinated or incorrectly performed, for example.

Each of the four areas of pilot information processing in the cockpit—perception, comprehension, decision, and action—can be affected by the design and operation of cockpit systems. Standard instruments, long familiar to the pilot, and standard usage of coded knobs and dials will increase the probability of perception. Signals arranged in a long practiced array and received without excess demands competing for pilot attention will be best comprehended. Errors in decisionmaking may stem from cockpit systems that are more complex or attention-demanding than is necessary. Finally, an action selection failure may be promoted by cockpit arrangements that make it possible to confuse one control with another, so that the pilot who means to do one thing actually does something else. Standard arrangements and logic of actuation are clearly among the means of reducing such action failures.

The preceding discussion of principles of safety is intended to make a case for the safety enhancement that can be obtained by increasing standardization in the cockpit. It is recognized that this is not the only way to reduce accidents; improved levels of pilot proficiency and currency plus the avoidance of flight in hazardous environments are complementary and, statistically, are even more important means of improving safety. The particular attraction of attacking the accident problem at the level of cockpit standardization is twofold. First, the standard use of well-designed and human-engineered cockpit systems may not cost any appreciable sum in the long run. If there were a rough equivalence in the number of accidents that could be prevented by standardizing certain cockpit systems on the one hand and by eschewing flight in reduced visibility conditions on the other hand, it is clear the the efficiency and utility of flight would be enhanced by making the improvement through increased standardization. As long as the weather is not completely predictable and is violent occasionally and as long as physical and human systems can suffer catastrophic failures, there will be some incidence of accidents. The only way to reduce aviation accidents to zero would be to ground all aircraft. By comparison, any increment of safety that can be obtained by using standard, convenient, and easy-to-use cockpit systems rather than variable, demanding, and hard-to-use systems seems to be extremely worthwhile, even though it is not a panacea.

DEFINITIONS OF GOOD DESIGN. In this report, phrases such as "well designed" or "human engineered," referring to cockpit systems, are used as shorthand to refer to displays, controls, cockpit layouts, and auxillary systems that conform to what is accepted as good engineering practice. There are general principles that enable one to determine whether a cockpit system is well designed, and these general guidelines should be stated.

Standardization is, itself, of very great importance in any complex task that is performed on the basis of past training and experience with similar or analogous systems. An everyday example is found in the typewriter keyboard. Even a beginning student of touch typing can determine that the standard "QWERTY" keyboard layout is far from optimum. It does not spread the workload equitably among the fingers, but standardization is of such overwhelming importance in a skill such as typing that we retain the traditional layout. The cockpit of an airplane presents both traditional tasks for which there are well-established population stereotypes, constituting old habits that may be relied upon, and also novel displays and controls that have been created specially for the aircraft situation. For each of these, the old and the new, there are generally accepted rules of human engineering that tend to ensure that the system is easy to learn and use, is resistant to serious error, and takes account of the special information processing capacities and frailties of human pilots.

Selecting a cockpit system for an "old" or traditional task, the paramount considerations are the following:

1. Anthropometric compatibility should be assured. Essentially, this means that the size, reach, and strength of the prospective pilots must be considered.

2. Unequivocal indicators and feedback must be used. For example, the pointer end of a selector handle must be clearly differentiated and the status information required to continue a closed-loop control system must not be masked.

3. All systems must follow population stereotypes as to logic of actuation, direction of increase, and "natural" relations, such as "turn left" to select the left.

4. Positive detents or other provisions to bar inadvertent actuation must be provided on all hazard controls.

5. Provision should be made for testing the status of systems, and indicators should have a clear failed-state.

6. Standardization should cover, where appropriate, the location, size, color coding, shape, labeling, feel, logic, and arrangement in relation to related systems of all important devices and systems.

In the case of a novel aircraft system without a common analogue in the experience of most nonpilots, a set of more general design desiderata may be stated:

1. The design should be based on a systematic study of both the purpose of the device and when and how the pilot uses it.

2. Information processing sequences should be considered so that there is the maximum distinctiveness and separation of confusable but incompatible systems.

3. Simplicity of display and action should be sought, recognizing that the system may have to be used in excess workload or "panic" situations.

4. The perceptual strength of the human in recognizing patterns of information should be considered in display design.

5. The response limitations of the human should be considered in design so that the pilot is not required to perform difficult and demanding coordinations.

6. Planning aids and feedback from responses should be included.

As in the example of the typewriter keyboard, it is possible to detect an occasional conflict between "good design" and capitalization on the benefits of standardization. Some aircraft systems have evolved and become nearly standard without necessarily incorporating an optimum application of all the design guidelines that have been mentioned. Hence, the concept of good human engineering of cockpit systems cannot be treated as an absolute any more than standardization itself can be elevated to that status. Guiding concepts of design are just that, guiding, not laws of nature. Likewise, total standardization of cockpit systems could be accomplished only at the sacrifice of the wide variety of aircraft types and uses; a sacrifice that would be as useless as seeking safety by grounding all aircraft in anything other than perfect weather. What must be done in the evolution of better regulations and design practices is to balance the demands of optimum human engineering design and the benefits of standardization with a keen appreciation of what is feasible, practical, and cost effective.

ALTERNATE VALUES OF STANDARDIZATION. In virtually all fields in which modern technology is applied, there is general agreement that a high degree of standardization is desirable. General evidence for this is found in the existence of numerous national and international groups devoted to single industry or broad-based standardization goals. The goals sought by advocates of standardization are diverse but at the same time compatible. Economy in the pure economic sense is important since parts, tools, and practices are reduced in variability and cost.

Parallel benefits are found from increased standardization in the design process. This occurs when information developed in separate engineering efforts is examined by groups devoted to industry standardization and knowledgeable about similar standardization programs in other domains, and a particular design solution is adopted as a recommended practice. Since complex aircraft systems must, of necessity, be composed largely of subsystems, design work is greatly reduced and facilitated if standardized component elements, proven in widespread application and recommended by some sort of guideline document, can be specified instead of making an attempt to design the entire assemblage de novo.

Another and significant kind of advantage that may be obtained by increased standardization relates specifically to the human elements in the operating system. Whether a mechanic or an operator, per se, the human being derives several benefits from working with standard equipment and procedures, and these benefits lead to major improvements in operating efficiency. If safety is important because of the type system in question, it is generally found that increased efficiency leads to increased safety. The causal chain here is based on those properties of man that make him a creature of habit and a creature with limited ability to learn. Standardization reduces the number of alternatives that must be available in the behavioral repertoire, particularly in the requirements for discrimination of just perceptible differences. The human processes data in such a way that if most elements of the data flow are identical or substantially similar to other but incompatible response situations, the fine-grain quality of the required discrimination increases the time and effort required. Furthermore, since habits are acquired one at a time and differentially reinforced in subsequent experience, the potential for error will be increased as a function of the absence of standardization. To the extent that the "habit pool" is reduced by standard stimuli and required responses, the possibility of a nonoptimum association between the immediate situation and the practiced or correctly learned links between stimulus and response is decreased. Human error then is seen as decreased in liklihood when the alternatives are reduced by standardization.

Having argued that the several benefits of standardization are well accepted, the question must be asked why is there not more standardization, in fact, why is diversity so powerful an impulse in system design? The full answer to this question again has several elements. First, it should be clear that just as standardization brings benefits, it brings important costs. Innovation is linked to the freedom of the designer to test alternative elements and configurations. It is not always easy to obtain results or feedback that leads to a definitive decision that the elected variations are or are not cost effective. Freedom to adapt previous designs and also to create entirely new design concepts for physical or procedural system elements is of the utmost importance for progress. This freedom, in turn, leads to increased efficiency, reduced costs, and increased safety. But it works counter to the urge to attain increased standardization. As suggested, also, the innovator may assess the results of his unique or changed design in a way that indicates a nonprovable benefit. Hence, several designers may hold out for the advantages of their different and incompatible designs, and it may not be possible to obtain the amount and kind of data that would settle the argument. This quandary is often seen in marketed products with styling variations intended to promote brand loyalty or identifiability. In aviation, this may extend to use of nonstandard design practices because of an idea that "old customers expect this company to continue to build a distinctive product with continuity of design." Here it may be seen that two versions of standardization are at war — standardization across an industry or type of product, versus standardization within a product family.

If a critical experiment could be performed in those instances of design differences that are thought to be directly related to safety such that clear data could be obtained showing that increased breadth of standardization did or did not enhance safety, it might be expected that such differences could be resolved. Such experiments are generally not feasible, however, and we must rely instead on natural data obtained over time and experience with the alternatives. Such reliance means that data are not available when needed, that is, when the decision is being made that the designer should or should not proceed with the nonstandard product element.

Another very important reason that more designs do not follow more completely those standardization guidelines that are now existent is that the application differs, and the demands of best-system-use mandate deviation from otherwise acknowledged standards. An instance of this factor may be seen in the different requirements of various classes of FAR 25 aircraft. Those aircraft built to be operated by two pilots clearly have different requirements for flight deck automation than those aircraft designed for three-crew operation. For example, if all the functions that are designed to be performed without human monitoring and intervention in the one aircraft were conducted in the same way in the aircraft with an additional crewmember, there would be insufficient primary duties for the third person. Since the third person in such a crew is the least experienced and least qualified crewmember, an overall monitoring or backup function is not sensible, and a command responsibility assignment is ruled out for the same reasons. With these options ruled out, the result would be a crewmember without an adequate job, a situation known to lead to inadequate performance of remaining duties and also likely to lead to interference with the primary duties of the more loaded crewmembers. Given this situation, the best design solution has been to reduce automation and ensure that the third person has necessary and important duties. This alternative is selected even when there is reason to believe that the level of flight deck automation employed in the aircraft with two crewmembers is superior in efficiency and represents the most likely "standard" of the future.

The temporal factor, alluded to above, constitutes another broad influence reducing the overall incidence of standardization. Since technology is a growth process, yesterday's "best" engineering practice, if incorporated in a recommended standard, may not be tomorrow's "best." As knowledge of newer improvements is developed, the standards change slowly. If every innovation was adopted as a recommended design practice on the basis of initial or minimum evidence of effectiveness, standards would be so fluid they would become meaningless. Hence, recommended practices have a tendency to endure beyond the immediate time period when it is very evident that most designs should conform. In the resulting "twilight" period, evidence is accumulated and weighed as to the need for change in the applicable standard. Ultimately, if the evidence becomes commanding in import and is disseminated throughout the relevant industry group, it is likely that a new standard will be promulgated. In some cases, the adopted solution to this problem may be to set forth an alternate standard or to propose a standard for use starting at some stated future date.

In this listing of reasons why more standardization is not seen, there is one more general influence that should be noted; this relates to the needs of the organization that is going to use the system in question. Ordinarily, complex and costly products of technology, such as transport aircraft, are acquired with the intention of gradual implementation in an ongoing enterprise and continuation of that utilization for a protracted period, such as 20 years. Furthermore, the maintenance and operating systems of the airline or other organization have important investments in tools and trained personnel. Sometimes we see the result of these considerations in an instance of non-standardization. The purchaser of an aircraft may specify that the flight deck include instruments, controls, or avionics subsystems that are similar to those installed in aircraft procured earlier or at a time when a different design practice may have been preferred or standard. In this way, the fleet operated by one organization is kept relatively standard, although this may imply the use of less than the most modern equipment or procedures. Since in many cases equipment passes from the fleet of one operator into the fleet of another operator before coming to the end of its expected useful life, the ultimate result of such attempts to increase within-fleet standardization may tend toward reduced industry standardization and reduced standardization in the fleet of second-level operators or lease agents.

At this stage of the discussion, it should be evident that the desirability of increased standardization in flight deck designs of transport category aircraft must be viewed in the context of a number of related considerations. This is why progress toward increased standardization is relatively slow. It is necessary to proceed in a careful way to evaluate the potential impact of each standardization action on the manufacturer or supplier, on the immediate user, and on the ultimate or long-range user, and to always keep in mind the need to encourage innovation and avoid any stifling of differences that have genuine utility for special applications.

All flight decks cannot be the same. At the same time, the mandate given the FAA to ensure compliance with safety makes some degree of regulatory standardization essential, and the interests of both manufacturers and aircraft operators make additional standardization highly desirable.

METHODOLOGY

The starting place for any analysis of standardization requirements should be the present status in this domain. Three lines of investigation were followed to determine this present status. First, the FAR's were examined to determine what standardization is required by regulation at this time. Second, the broader literature was surveyed, including papers that might suggest requirements for increased standardization and publications of industry groups interested in standardization as related to transport aircraft. Finally, visits were made to aircraft manufacturers and to airlines to determine the present thinking of a representative sample of industry experts. The information obtained in these initial activities will be summarized at the beginning of the Results section of this paper.

Since the ultimate objectives were to determine whether additional standardization is required, and if so in what specific areas, and then to go on to the related matters of identification of best designs for standardization and most appropriate methods of implementation, the major portion of the Results section will be devoted to these matters.

The author, an engineering research psychologist employed by the FAA, conducted the initial literature search. Subsequent contacts with airline operators were made by an FAA team made up of the author plus one or more engineering test pilots and flight operations analysts; all team members had extensive experience as airline pilots in line service prior to their employment by the FAA. Inquiries made with aircraft manufacturers about standardization matters were conducted in the course of other project activities by the same psychologist with the assistance of one or more experienced pilots employed by the FAA.

Airlines visited included three certificated air route carriers, usually classified as domestic trunks although all three have international service, plus two smaller certificated carriers that were formerly classified as supplementals. Both of the latter operated diversified fleets of FAR 25 aircraft, many of which were originally ordered by domestic trunks and later were acquired by the second level carriers. Manufacturers surveyed were the three principal manufacturers of turbojet transport aircraft.

When visiting an airline, the normal procedure was to interview personnel of both the training and engineering departments and to sit through one or more crew training sessions. In addition, management personnel were interviewed, when available, to investigate policy questions, particularly those relating to dual qualifications of crews, crew scheduling including different aircraft types, and interest in increased standardization of new aircraft procurements. No formal questionnaires were administered, but interviews were conducted with a structured outline that tended to ensure coverage of similar questions at various data sources.

The principal contacts at aircraft manufacturers were with management personnel and engineers engaged in crew station design programs for new aircraft. The senior people in the training department of one manufacturer were also seen.

In the usual course of travel duty over a 2-year period, the writer was authorized to ride in the cockpit and, in so doing, interviewed 12 crews that were flying turbojet aircraft. Altogether, it is estimated that 75 airline pilots, about evenly divided between members of line crews and pilots permanently or temporarily assigned to airline headquarters, were included in the sample providing information. About 10 of these pilots were also engineers and had primary assignments in design and test work. Another 10 engineers without line crew experience were interviewed.

Because each airline has contract arrangements with its pilots governing the bid process for duty assignments and the whole topic of crew scheduling is considered to be "sensitive," no direct requests were made to airlines for the pilot run selections and crew sequences. Therefore, no definitive answers were provided to questions as to the occurrence of dual qualifications and the incidence of pilots switching from one type aircraft to another during a given month of flying. Since it was felt that questions in this area had at least peripheral importance to the major topic of flight deck standardization, inquiries were made in a discreet manner. None of the airline management persons who were interviewed could be induced to volunteer the desired factual data, but several line crews were less defensive on the subject and did supply the project team with copies of the current pilot status reports and crew sequences. These were obtained from only two trunk carriers and then from only one crew domicile for each airline. Based on various discussions with individual crew members at other airlines, it is suggested that the small sample of pilot qualification data and scheduling information is reasonably representative of industry practice. It is clear, however, that no absolute conclusions can be determined from these data.

All of the inquiries began with general questions relating to standardization in the current aircraft fleet and with requests for diagrams of the various flight deck panels. In some instances it was possible to obtain pilot training "introductory" booklets on the different aircraft, and these were found to contain explanatory material that was valuable to understanding the differences in instruments, controls, and systems indicators. Having obtained the contact's views on the current status of flight deck standardization and the importance of both uniformity and fleet modernization, the discussion proceeded to more specific questions. Subjects were asked to cite instances that had occurred in either line operations or in training that indicated deficiencies of flight deck standardization. Since most fleets contain both first generation turbojets (B-707 or DC-8) and later designs (B-727, B-737, DC-9) and also wide-body aircraft, it was possible to prompt the interviewees by pointing out (1) the evolutionary changes that have occurred in basic flight instruments and altimeters, (2) the relatively recent divergences from standardization in engine instrumentation, (3) the wide differences in flap and leading edge systems, and (4) the many changes in systems displays. Hence, the pilot's main instrument panel, the center console, the overhead panels, and the various flight engineers panels were reviewed in turn. With this eneral review accomplished, subjects were asked to state the degree of importance attached to increased standardization in six primary areas: flight guidance systems (including flight director, raw data displays of attitude, direction, speed, and altitude, and warning annunciators); altimeters; flap, slat, and leading-edge device systems (including hydraulic and manual reversion systems); power-plant instrumentation; indicated airspeed (IAS)-Mach indicators; and electric power and hydraulic power systems.

Finally, interviewees were asked to state opinions of other areas of flight deck design that should be more standard. During interviews at the first airline visited, it was found that there is great dissatisfaction with the input devices and displays of the avionics systems, so this category was added to the six others in future rounds of inquiry. Free ranging discussions included various additional topics. In effect, the subjects interpreted our questions as an invitation to tell what is wrong with human engineering on the flight deck and which provisions are inconvenient, confusing, uncomfortable, etc. Topics quite far afield, such as the general dissatisfaction with emergency escape provisions (side window that opens and a rope in a box overhead), the expensive but not very useful sun shields (plastic plates that are capable of falling in the pilot's face in a busy moment on final approach), and the inconvenient eating facilities paired with inadequate seats, were brought up time and again. It was thought that even this kind of information had some use to us, and on long flights there was plenty of time to speak of gripes and odd experiences with flight deck equipment. We heard no end of anecdotes such as the incident of the DC-10 pilot jabbing at the button that silences the gear warning horn and inadvertently turning down the volume of the radio losing the air traffic control (ATC) communications. Murphy's law has operated for most pilots at one time and another, and the resulting stories poured out. Our effort was, however, to return the focus to the question of how standard are the aircraft and the question of how standard they might be.

When a particular system was identified as potentially benefiting from increased standardization, the first followup made was to inquire as to the best possible design guideline which could be made in future standardization efforts. This is to say that opinions were solicited on how to solve identified problems. Then, in cases with specific proposed solutions, the question was raised, How do we know that this is the best design; are there data from a comparison test or other evidence? The goal here was to identify problems for future study, particularly instances of disagreement as to the optimum design or situations that might best be resolved by test.

The justification given for setting priorities on specific areas of flight deck design was always safety. While practicality was generally included and the tendency toward blue-sky solutions was avoided, we found the safety rationale for standardization well understood and well accepted. Airline training departments are heavily engaged in upgrade training, from one seat to another in the same aircraft, and in transition training, from one aircraft type to another. Since, as mentioned, fleets included turbojet aircraft designed over a rather long time span, the identification of differences requiring specific attention in transition training is a major responsibility. Similarly, during training, line pilots are made aware of these differences and are well informed about the possibility of pilot errors that may stem from differences in the location of switches or information displays and differences in handling feel or control forces appropriate to make particular corrections in one type aircraft versus another. Because of awareness of these possibilities and attention given to differences, subjects were found to respond well to the concept that future standardization efforts should concentrate on safety related systems. Only in discussions with manufacturers or airline engineers were the economies of increased standardization frequently mentioned. All three manufacturers indicated that flight deck standardization was a corporate objective. In particular, one manufacturer suggested that the best cockpit would be a module that could be attached to any aircraft built by that company, whether the smallest two-engine aircraft or the largest wide-body aircraft. Airline people did point out the history of various standardization actions taken over the recent past; participation in developing a system for shared inventory and supply of spare parts; attempts to obtain agreement among those airlines making the initial purchases of a new transport aircraft type on the flight deck provisions; and representation on industry committees (particularly those sponsored by the Air Transport Association (ATA), with commitments to flight deck standardization in both equipment and definition of standard pilot duties and procedures). While money economies were related to these standardization concerns, there was also an expression of concern for ease of training, for reduction of delays caused by absence of a unique repair part at a particular airport, and for possible aircraft exchange flexibility, lease arrangements, and future changes in fleet composition through the acquisition of used aircraft for the overall benefit of the industry. We learned that an airline may take over aircraft delivery positions that have been reserved by another airline as much as several years before. This may necessitate costly and time-consuming retrofits after the aircraft is delivered; such adjustments are required to ensure fleet standardization. A similar situation develops when aircraft are exchanged or leased for a season or for peak traffic periods.

Following completion of the inquiries with airlines, with manufacturers, and with line-crews, two additional phases of project activity intervened before preparation of this report. Availability of a summer employee made it possible to launch a specific investigation of one restricted field of standardization, that of metrification. The literature on metrification in aircraft instruments was examined, and flight deck panels were studied to assess the degree of agreement already attained on use of metric quantities both in U.S. built aircraft and in the Airbus A-300. Finally, at the suggestion of the Office of Systems Engineering Management, additional inquiry was directed to industry committees, such as the Society of Automotive Engineers (SAE)-S7 group which is devoted to flight deck design and handling qualities, and to offices of the Department of Defense which have related interests in cockpit standardization.

As may be concluded on the basis of the previous outline of the methods employed, this is a very large topic for investigation. The present study was a small-scale effort, amounting to about 1 man-year total effort spread out over three persons and 2 years. Hence, the results must be understood to be preliminary and incomplete. A much larger investigative effort would be required to achieve final answers to many of the relevant issues.

RESULTS

PRESENT STANDARDIZATION REQUIREMENTS AND GUIDANCE.

At the present time, transport category aircraft flight decks exhibit a considerable degree of functional standardization that is the product of a longstanding effort in the industry and government. As well accepted as many such instances are, it is difficult today to identify the actual origins of the basic T arrangement of flight instruments; many have claimed preeminence to its paternity. The Air Force at Wright-Patterson, the Airline Pilots Association, the FAA, and various industry groups have been given priority in one publication or another. This illustrates the diversity of standardization sources and the high level of priority placed on standardization.

In the U.S. Department of Defense there has been, for many years, a military standard document requiring conformance of man-machine interface provisions with human engineering principles. This has increased standardization and has flowed over into commercial aviation, since the same manufacturers and instrument suppliers are involved and many leaders in civil aviation have had military experience. In addition to military standard 1472C, the Air Force promulgates a detailed handbook series on engineering design and standardization (HIAD-AFSCM 80-1 "Aircraft Design" and HIAPSD-AFSCM 80-3 "Personnel").

Many industry committees are involved in the continuing efforts to improve flight deck designs and ensure a suitable degree of standardization. SAE committees include as members both user representatives, in this case airline pilots, and manufacturer representatives. For example, the S7 committee (Flight Deck Design and Handling Qualities) is made up primarily of pilots drawn both from active line ranks and from airline management and engineering, but also includes National Aeronautics and Space Administration (NASA) and FAA liaison personnel and manufacturers representatives. The more focused efforts of the SAE A4 and A7 groups, devoted respectively to aircraft instruments and aircraft lighting, also impact standardization on the flight deck and are managed by groups somewhat less linepilot oriented and more technical in specialization. All of these SAE groups contribute to flight deck standardization by identifing problems and design alternatives, discussing effects on safety and efficiency, and publishing voluntary design guidelines called Aeronautical Recommended Practices (ARP's).

The Air Transport Association (ATA) sponsors a Flight Systems Integration Committee, made up primarily of airline pilots and engineers. This committee reports on pilot display systems and guidance elements to the Operations Committee of the ATA, with a primary goal of increasing technical standardization.

Aeronautical Radio, Incorporated (ARINC) sponsors the Airlines Electronic Engineering Committee (AEEC), which publishes numbered specifications for a wide variety of electrical and electronic systems in the aircraft. Many of these specifications go beyond size, electrical characteristics, and performance considerations and have the effect of man-machine interface standardization guides as well. ARINC maintains close rapport with such military groups as the U.S. Air Force Armament and Avionics Planning Conferences, which also involve cockpit standardization efforts. In fact, AEEC may be one of the best informed sources for guidance in problems relating to computer system cockpit interfaces since that committee has worked for some years on characteristics for the flight management computer, the flight warning computer, the digital information transfer system, and related topics. ARINC 700-series specifications are considered the backbone of digital aircraft design and include 30 different specifications for the next generation aircraft digital avionics.

Completing the present sources of guides for transport category aircraft flight deck standardization are the FAA Airworthiness Standards, Part 25, containing 12 pages of rules under Subpart F, "Equipment." Several of these rules state that a specific warning device must be installed, and the FAR may cover such specifics as the nature of the required warning signal. Other requirements for indicators are more general; e.g., the case of the requirement for fire warning indicators for powerplants. Since all FAR 25 turbojet aircraft that we know of have an actual bell for an aural engine-fire warning (recent models have a synthetic sound modeled on that of a bell) in addition to the master visual warning, it might be assumed that this is one of the instances of "specification in the FAR's" of the characteristics of the warning. This is not the case, however, and a recent report by Boeing indicates that the "bell" standardization traces from an SAE ARP. Additional cockpit standardization guidelines are found in other sections of Part 25.

The FAR's vary from system to system not only with regard to the degree of specificity, as suggested with various warnings, but also with regard to applicability to the newer, integrated digital systems. Most of the airline and aircraft manufacturer personnel interviewed in this study agreed that regulations which have the force of law should be written to define necessary performance standards, rather than spelling out exact system descriptions, installation, or power. There are, for example, many ways of making instruments visible in the dark or in weak light. FAR 25.1381 states that instrument lights must make each instrument, switch, or other device easily readable, but does not prescribe or proscribe any of the various lighting techniques.

The consensus seems to be that it is a mistake for the FAA to mandate a special device or instrument. Rather, a necessary function should be enumerated, and the applicant for certification should be required to demonstrate attainment of that necessary function. Specifics should not be stated in the FAR's because technology advances faster than law and the result of such over-definition may be to hold back progress. This is not to say that our industry and airline informants do not want additional agreements on standard system interfaces at both the aircraft and pilot junctions. Rather the common opinion appears to be that the industry, operating through its various advisory committees, is better able to ensure the currency and adequacy of detailed standardization guides. In particular, necessary changes can be accomplished sooner. If the general trend of standardization actions by the FAA should follow this industry suggestion in the future, it would appear to be increasingly important to have FAA technical representation on all such industry committees.

THE NEED FOR INCREASED STANDARDIZATION.

The first point that must be recognized is that standardization is a critical juncture in the progress of commercial aviation. The enormous progress made in the development of computers and computergraphic displays is about to produce a revolutionary set of changes in flight deck design. Functions are being automated which reduce the number and complexity of displays and controls. CRT and other large screen transilluminated and computer-generated displays are replacing hard-wired, single-purpose indicators. Caution and warning systems are becoming "smart" so that they give priority to what is important and provide stored information to guide corrective action instead of merely signaling out-of-tolerance conditions. These are but a few of the changes that are in progress. Others include additions of the head-up display in several forms; e.g., new avionics for advanced navigation systems, data link, new separation displays related to concepts now being tested—Cockpit Display of Traffic Information (CDTI), Automatic Traffic Advisory and Resolution Service (ATARS), Collision Avoidance System (CAS)—flight management systems for fuel-efficient flight, etc.

Certainly, since the initial introduction of turbojet aircraft in the late 1950's, there has been no equivalent period of rapid change. The adoption of the Electronic Flight Instrument System (EFIS) for the next Boeing transport aircraft to be introduced into the system has alerted airlines and pilots to the importance of the imminent changes. While military agencies have some considerable experience with electronic displays as replacements for the electro-mechanical generation of devices, there is little commercial experience on which to draw. Furthermore, the great importance of software represents a change for which we are little prepared. A computer generated electronic display may be completely reconfigured by software changes. For example, the size, color, intensity, steadiness, and organization of elements may be under program control, and in some planned systems, any particular display surface may be switched to provide primary flight information, powerplant data, systems status, checklists, cautions and warnings, weather, navigation, or nearby traffic information, plus various combinations.

These flight deck systems are so radically different from those certificated under the existing airworthiness standards that the question must be raised, do we need to be concerned that the present level of standardization does not break down? It would be entirely possible to imagine that various manufacturers, working with different computer and avionics suppliers, and catering to the preferences of various domestic and foreign initial aircraft purchasers, might introduce radically different total systems. Standardization guidelines that require only physical arrangements and functional characteristics do not necessarily exercise any restraints on the possibilities for software variations that could make aircraft flight deck displays more variable than those in the present fleet.

The implication of these developments is that computer generated (i.e., program controlled) flight deck systems must be tested and certificated as systems with software included. Furthermore, display format guidelines are urgently needed since the inherent flexibility of electronic display frees the instrument designer from many of the practical constraints of the past. Many flight deck elements in the past were functionally similar, not because of the requirements of standardization guidelines, but because of the limited alternatives, given a standard instrument case size and the existing mechanical constraints. Large-screen electronic displays generated by computer elements will greatly increase design flexibility by removing such constraints.

A very strong consensus was demonstrated in our discussions with manufacturers, airlines, and individual line crews favoring near-term action to protect at least the present level of flight deck standardization and advocating particular attention to the new challenges of software controlled systems. In view of the competition among manufacturers for future sales and the evident pride of design teams in the individual advances and improvements that each has made in flight deck design, it is generally held to be self-evident that the government must play a strong role if such standardization is to be achieved in the future.

At the same time that we found wide recognition of the need for near-term government action to ensure future standardization, we were made aware of a concern that such action would not delay or impede progress. The present situation is most difficult because aircraft with many of the new electronic systems will be manufactured simultaneously with conventional aircraft with flight decks that have changed only slightly through the years. Regulations and guidelines must be written to cover highly diversified situations and at the same time to hold designers to more stringent requirements now that many of the previous design constraints have been removed by technical progress.

It seems evident that the challenge presented by the electronic revolution requires an expanded and broad-based FAA effort. While the military services have the most in-flight experience with the new systems for display, control, communication, and navigation, the automation industry is actually moving ahead with new systems even faster in nonaircraft contexts. It would appear that revisions in FAA standards should be guided, in part, by the best distillation of information available through various sources outside the field of commercial aviation. This is a major change. In the past, air-carrier aircraft were more similar to similar-sized military aircraft in flight deck equipment and layout and both shared many devices in common. Now, only the military have fully digital systems in regular service, and potential suppliers of future systems are even racing far ahead of the present military applications.

AREAS OF DESIGN REQUIRING INCREASED STANDARDIZATION.

The number one priority for specific areas of flight deck design, after the general requirement to ensure standardization of electronic and computer controlled systems, was the pilot input and input verification provisions of cockpit avionics systems. At present there are one or more keyboards in every turbojet transport cockpit. At the very least a hand-held electronic calculator is used to compute weight and balance, estimated arrival times and related numbers. Most aircraft also have keyboards for the insertion of waypoint data in navigation systems such as area navigation, inertial, or long range navigation (LORAN)/Omega. Newer aircraft have keyboards for fuel management computations and other functions. Unfortunately, the keyboards and associated readouts are deficient in two areas. First, they are generally part of independent, "strap-down" units, complete in and of themselves, so that they can be moved to other aircraft or replaced for maintenance. This independence results in restricted available space making the keys hard to differentiate and the displays hard to read. The second disadvantage of the present input facilities is that the configurations are nonstandard. The three major variations of keyboards, readouts, and function selector sequences are illustrated in figure 2.

Just as there are two facets of the problem with these pilot input keyboards, there are two suggested answers. First, most future aircraft should be designed to provide a centrally located space for a master pilot digital input system. While many are aware of alternatives to keyboards (moveable individual keys or buttons), such as touch displays or voice entry systems, it is generally believed that a keyboard data entry device will be needed for one or more flight deck functions for the

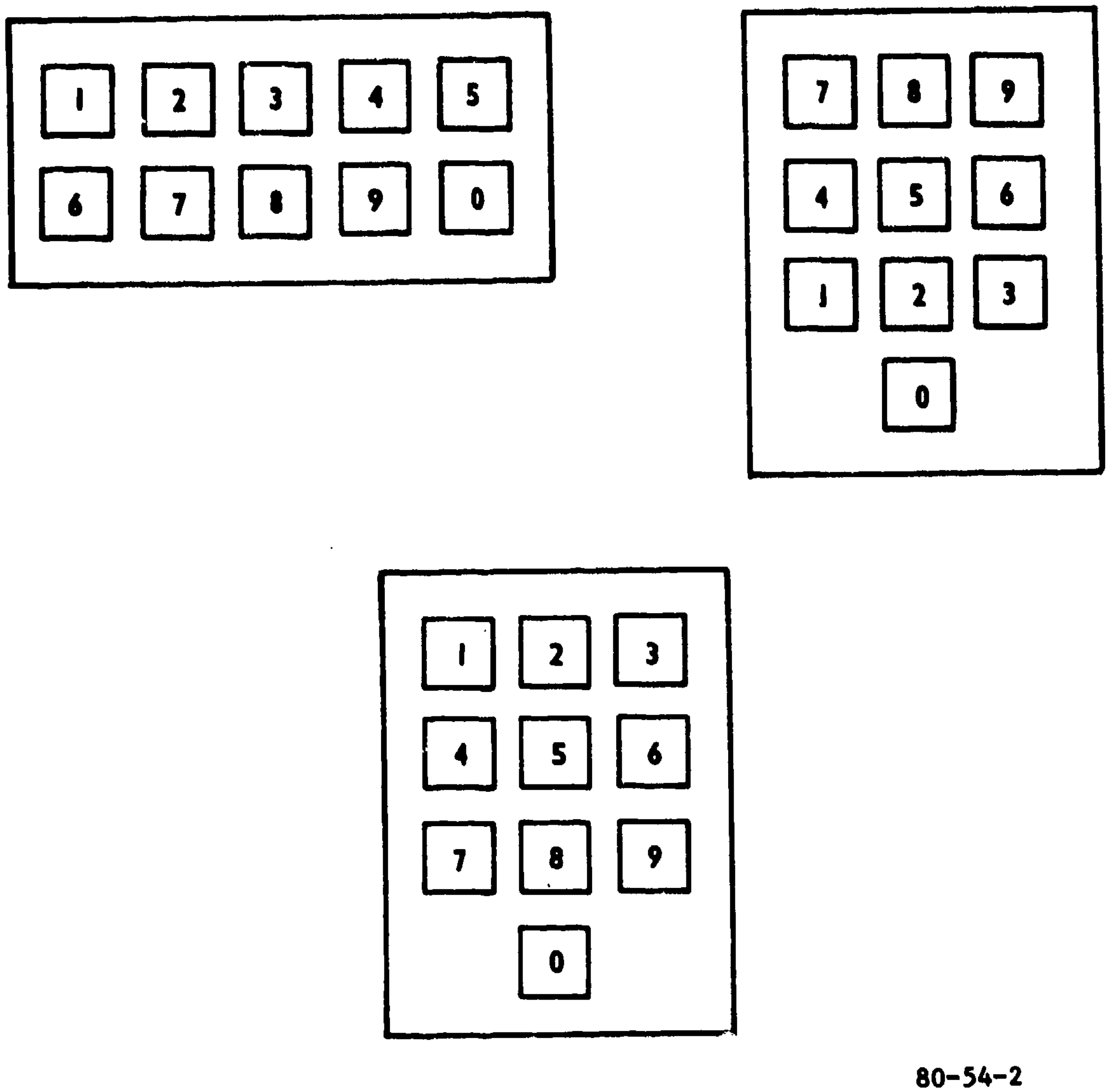


FIGURE 2. RNAV KEYBOARD, READOUT, AND MODE SELECT VARIANTS

indefinite future. Hence, a suitable location should be provided in contrast to the current practice of simply adding small, separate keyboards wherever they can be squeezed in. The aforementioned master input device should be large enough to permit use of large and well-separated keys. This will reduce entry errors, particularly under difficult turbulence conditions. There is general agreement that the verification readouts also need to be larger, for clarity, as contrasted to the present smaller readouts.

Second, pilots want one standard layout of numerical keys. It is proposed that the SAE publish an ARP to cover this topic. Similarly, the layout of the readouts should be made more uniform as should the order of mode selections, with the "off" position at the extreme counterclockwise limit of travel, followed by "standby," if any, and some uniform sequence of operating modes.

In the initial questioning of aircraft manufacture and airline representatives, we asked, "Apart from all integrated master caution and warning system, what are the principal safety-related cockpit interface systems most requiring standardization?" The order of priorities given by our informants was the following:

1. Flight guidance system, including both the flight director and the raw data displays.

2. Altimeters.

3. Flap and leading edge device control systems, including both hydraulic and manual revision systems.

4. IAS-Mach indicators.

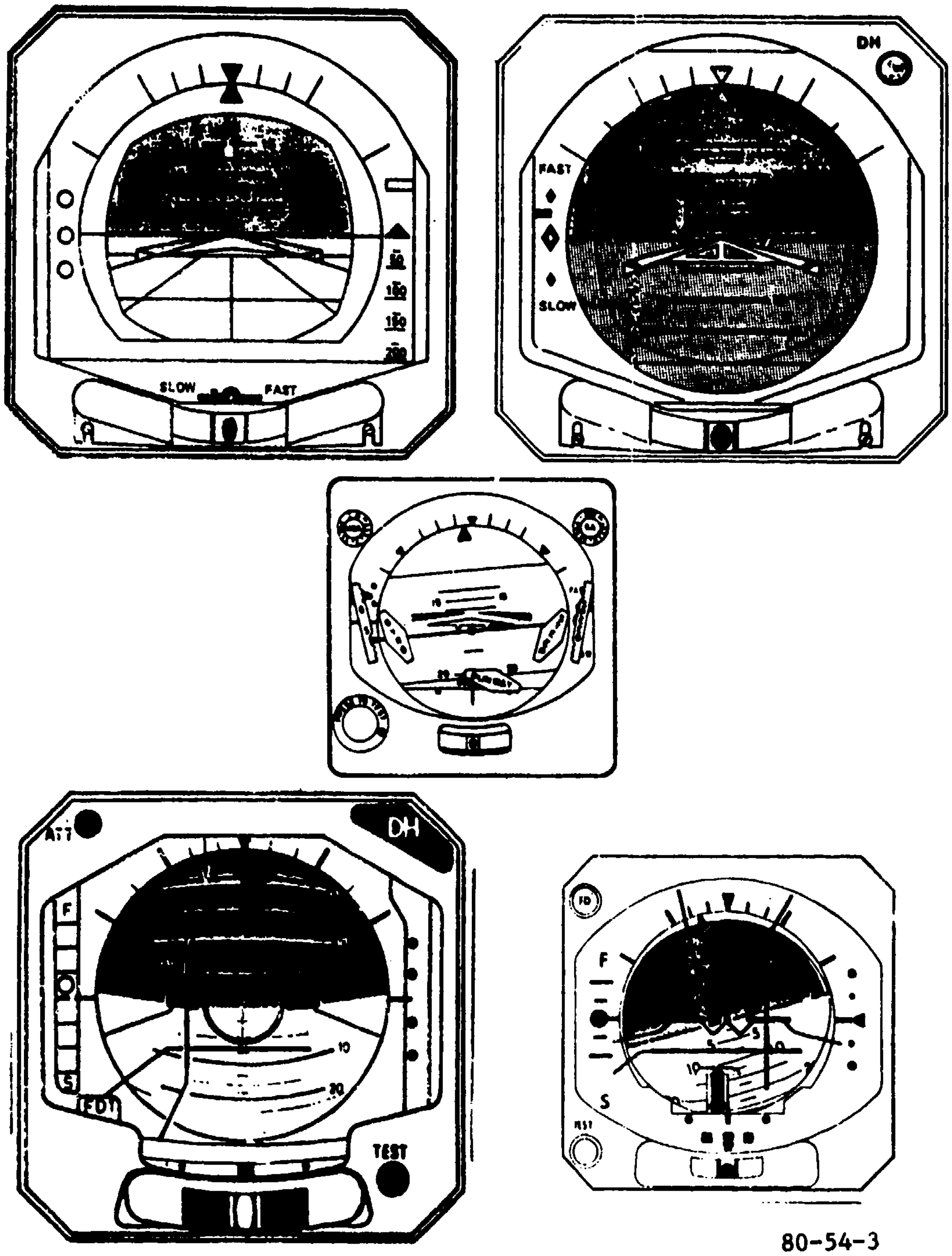
5. Powerplant instrumentation.

6. Electric and hydraulic power systems.

As discussed earlier, avionics keyboards, readouts, and mode selections were more frequently cited than any of the above six. Generally these were put into the category of "needs better human engineering design and standardization" for workload reduction and ease of operation, rather than for urgent safety considerations.

The standardization deficiencies of flight guidance systems are well known. Since final approach and landing, the missed-approach maneuver, and initial takeoff climb are the most critical phases of flight from an accident/incidence point of view, the flight director aircraft attitude display is most critical for safety. Studies have shown that the pilot flying the aircraft devotes most of his head-down time to this display in these near-the-ground maneuvers, and for this reason the out-of-tolerance indications given on the flight director are of great importance. It is unfortunate, then, that the various indicators are not standard in element arrangement. Glideslope deviation (high-low) and airspeed deviation (fast-slow) are sometimes reversed in location, and other elements may be varied in both location and essential form coding. Figure 3 shows variations in five attitude directors that are currently in use.

Airlines contacted in this investigation have made certain that any given aircraft series flown by various pilots holding that type qualification will have the same flight director installation and will have essentially identical displays of altitude, speed, and backup displays of attitude and direction. Two instances were noted, however, of two flight director versions installed in one type, although these alternate versions did not exhibit the radical differences in information placement and coding that are found in the most extreme director differences.



80-54-3

FIGURE 3. VARIATIONS IN CURRENT ATTITUDE DIRECTORS

Within a fleet of different aircraft types operated by one airline, the more radical differences do occur, leading to a possible problem for both a pilot with dual qualification and one who has recently transitioned.

This lack of flight director standardization is a possible fore-warning of what may happen with the new EFIS. Our informants placed great priority on agreement on the general patterning of these critical flight guidance displays before even the modest present degree of standardization is lost in a proliferation of EFIS versions. Figure 4 illustrates one variation in proposed EFIS displays.

It is considered equally important that attention be given to standization between the proposed head-up displays and the new head-down directors. Two formats presently being investigated are shown in Figure 5.

Altimeters constitute the flight deck display element that has been most studied in human factors laboratories over the years. When aircraft began to fly at higher altitudes and all three pointers in the classic three-pointer altimeter were off the peg, it was noted that several reading errors were possible. Substitution of a drum rolling on a horizontal axle allowed elimination of one pointer, and the further addition of a counter in a window in the later counter-drum-pointer version brought down the number of hands to one. Finally, provision of an electrical power source operating off an air-data computer allowed the development of the best and safest of all altitude display — the five-window, all-digital readout with either a thin pointer or an illuminated pip moving around the outer dial to indicate trend.

Judging from our pilot sources, there is universal agreement that the best altimeter is an all-digital (five numbers in a horizontal row) display. Sometimes the last two digits are tied together in 10- or 20-foot steps to avoid constant oscillation and unnecessary precision. The outer ring display is sufficient for fine grain resolution to the accuracy limit of the source and pressure setting. In transport category aircraft, there seem to be two problems standing in the way of standardization on this best altimeter. The first is simply the age of some aircraft still in use, and the need to keep all units of one type standard. We found three-pointer altimeters still in use in turbojet transports. Second is the cost factor. Since separate data sources are required to provide a true cross-check and verification,if both primary front-panel altimeters were all-digital, two separate air-data computers would be required. The counter-drum-pointer altimeter can revolve the lower unit-of-change drum from the raw barometric source, in contrast, providing independence without adding the cost of a second computer that converts the aneroid force into an electrical driving signal. Hence, counter-drum arrangements survive in current production aircraft, despite the well-documented cases of misreading when the counter is between notations.

The advent of EFIS should certainly ensure full digital altitude indications. Our pilot sources provided a majority opinion, however, that standardization action should be taken to cover the conventional flight displays. Pilots apparently want to eliminate the last three-pointer altimeters and want to set at least a timetable goal for universal installation of all-digital, clear-counter displays.

Radar altimeters vary widely. Vertical tape and round dial displays are the two main types; but color, graduation, and coding variations exist in each type. While there was no overwhelming consensus among our panel as to the best

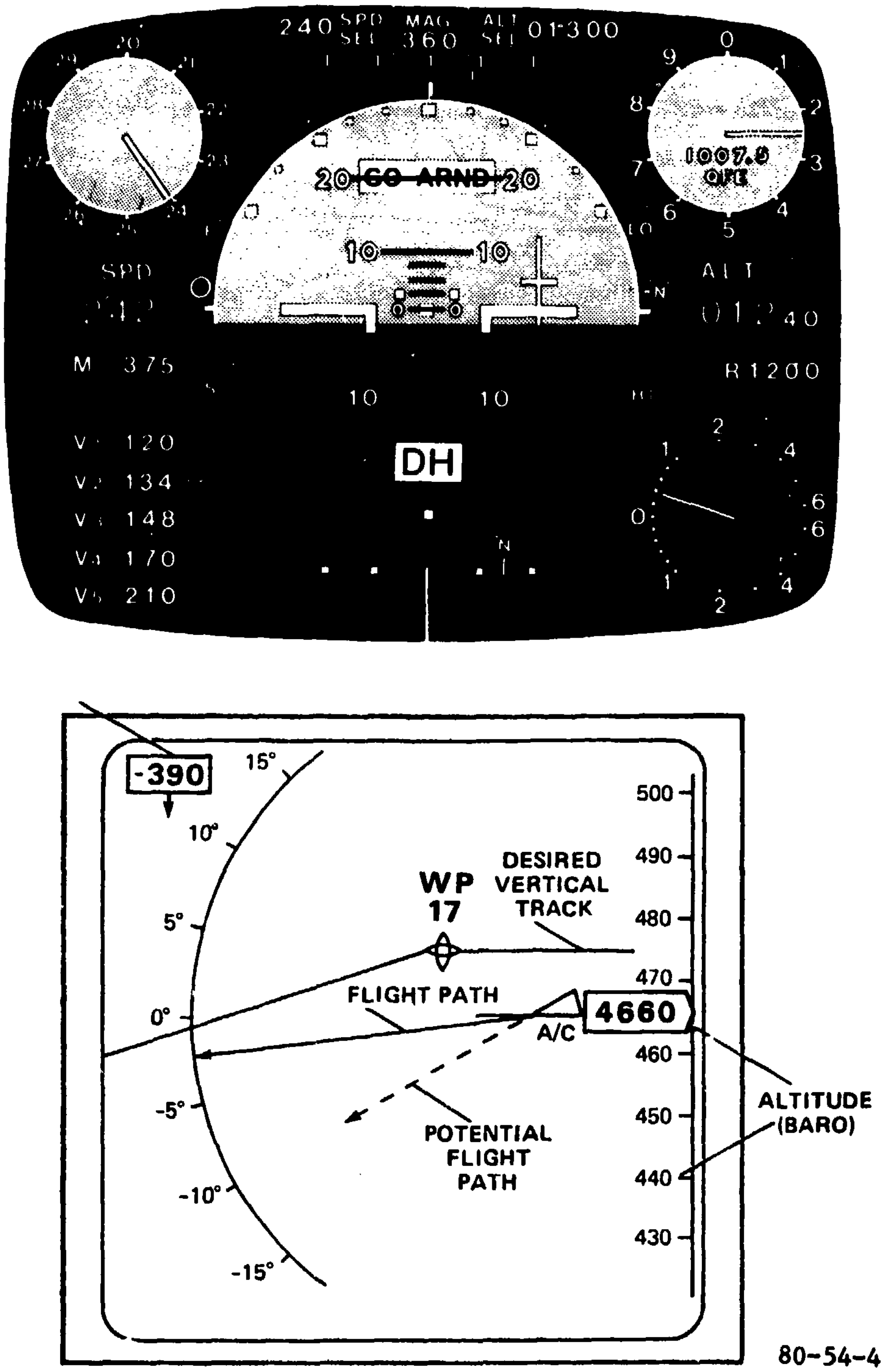


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FIGURE 4. ALTERNATE VERTICAL SITUATION DISPLAYS IN THE EFIS

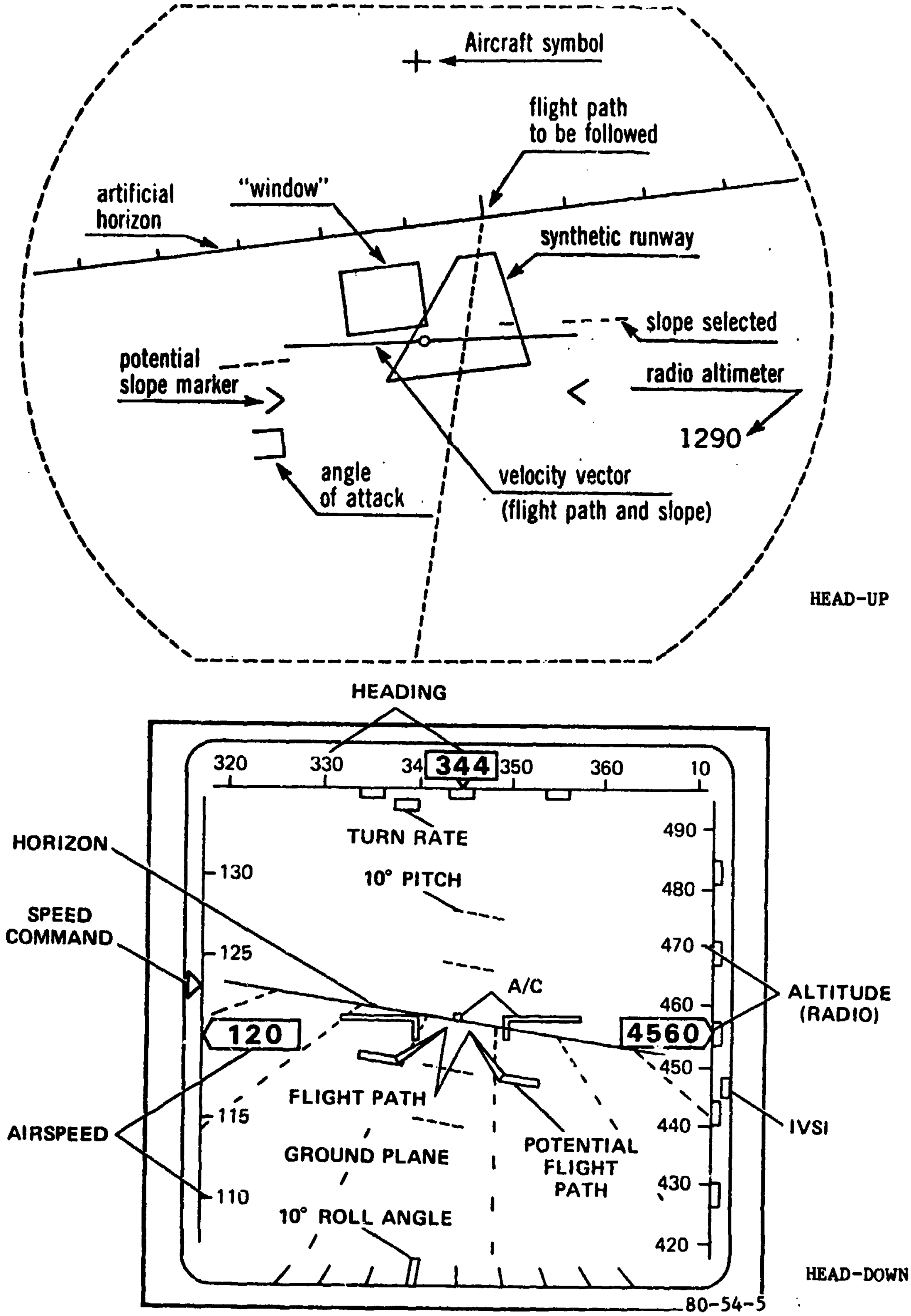


FIGURE 5. HEAD-UP VERSUS HEAD-DOWN VERSIONS OF APPROACH SYMBOLS

design, two points of interest were made. First, since the radar altimeter is often placed between the attitude director and the primary altimeter, the vertical tape instrument may be preferred because it is narrower. Second, standardization across types operated by any one airline is desirable. The present situation with regard to altimeter variation at one single airline is illustrated in table 1.

Flap and leading edge device systems are widely different both in physical properties in different aircraft and in standard procedures for deployment and retraction.

Generally, the widely different control and status indicator systems examined in the current airline fleet conform to the dictates of good engineering practice. Indicators are adjacent to controls, detents are provided for commanded steps, and status indicator lights and scales are placed on the front panel in the primary scan area. There is, however, enormous variation; almost every aircraft type is different. Some aircraft go from "up" to 0° to 15° then 22°, etc, while others go from main detents at 0° to "one up," 14°, 25°, etc. Typically, there are two dials for outboard versus inboard, and each may have dual needles to show status of left and right devices.

There was no general consensus about what should be done to achieve greater functional standardization in the area of flap-slat-leading edge device systems, but it was indicated that the present level of differences increases the training requirements and tends toward some degree of habit interference. It is suggested that this area should be highlighted for attention by appropriate industry committees.

Unlike the situation with flap systems, there are few aircraft differences that underlie the observed differences in indicated airspeed and Mach indicators. Designers' individual preferences appear to have ruled, and no reasons are known to delay in seeking a higher degree of standardization by industry agreement.

Powerplant instruments exhibit differences stemming from both physical differences in the equipment (primarily whether power is chiefly monitored by pressure ratio or by turbine stage speed (RPM/N1)), and design preferences as well (round dials versus vertical tapes). For some years vertical tapes were more expensive and less reliable than round dial instruments, although recently such cost differences have narrowed. Certainly, cost differences will not be a major basis for choice in the EFIS. Until the wide-body aircraft were introduced, virtually all civil turbojets used round dials (with differences in vertical sequence) with fuel flow on the bottom line monitored for engine balance or "trimming throttles." In the DC-10 wide-body series, airlines selected either vertical tapes or round dials, and the same choice was made in L-1011 purchases. Hence, several airlines have now lost the previous standardization on round dials across types operated by the airline. We believe the trend is toward vertical tapes, although all Boeing series still use round dials for most power indications. Human engineering guides often suggest that vertical tapes are better for quick scanning to check agreement and that deviations are more notable in peripheral vision. In part, this is probably due to the wider stroke width of the columnar index.

One possible disadvantage of the vertical tapes is that the arrangement of pressure ratio to the captain's side and fuel flow to the first officer's side may be slightly less convenient when the copilot is monitoring the performance, as opposed to having the primary power index across the top and fuel flow across the bottom. Each engine, then, is represented by a vertical row of instruments bearing the same left-right sequence as the actual

TABLE 1. ALTIMETER VARIATION AT ONE AIRLINE (Sheet 1 of 4)

	DC-10						
	Capt			1st Officer		Preselect	2nd Officer
	P	BU	R	P	R		
1. Full Counter to 20 ft Pointer: 360° = 1000 ft	X			X			
2. Drum for Thousands Pointer: 10 Units X 100 ft		X					
3. Radar-Green Over Str. Vertical Tape			X		X		
4. 3-Pointer 10000, 1000, 100							
5. 2-Pointer Flt Inside Cabin							
6. Vertical Tape Flt on Left, Cabin-R							X
7. Drum-Pointer Flt Drum Inside Cabin Pointer							
8. Command Altitude 5 Digit Counter						X	
9. Command Altitude 3 Digit Counter Plus Fix 00							

Legend

P - Primary
BU - Backup
R - Radar

TABLE 1. ALTIMETER VARIATION AT ONE AIRLINE (Sheet 2 of 4)

	DC-10						
	Capt			1st Officer		Preselect	2nd Officer
	P	BU	R	P	R		
1. Full Counter to 20 ft Pointer: 360° = 1000 ft	X			X			
2. Drum for Thousands Pointer: 10 Units X 100 ft		X					
3. Radar-Green Over Str. Vertical Tape			X		X		
4. 3-Pointer 10000, 1000, 100							
5. 2-Pointer Flt Inside Cabin							
6. Vertical Tape Flt on Left, Cabin-R							X
7. Drum-Pointer Flt Drum Inside Cabin Pointer							
8. Command Altitude 5 Digit Counter						X	
9. Command Altitude 3 Digit Counter Plus Fix 00							

Legend

P - Primary
BU - Backup
R - Radar

B-707

	Capt			1st Officer		Preselect	2nd Officer
	P	BU	R	P	R		
1. Full Counter to 20 ft Pointer: 360° = 1000 ft		X					
2. Drum for Thousands Pointer: 10 Units X 100 ft	X			X			
3. Radar-Green Over Str. Vertical Tape			X		X		
4. 3-Pointer 10000, 1000, 100							
5. 2-Pointer Flt Inside Cabin							
6. Vertical Tape Flt on Left, Cabin-R							
7. Drum-Pointer Flt Drum Inside Cabin Pointer							X
8. Command Altitude 5 Digit Counter							
9. Command Altitude 3 Digit Counter Plus Fix 00						X	

Legend

P - Primary
BU - Backup
R - Radar

TABLE 1. ALTIMETER VARIATION AT ONE AIRLINE (Sheet 4 of 4)

	B-727						
	Capt			1st Officer		Preselect	2nd Officer
	P	BU	R	P	R		
1. Full Counter to 20 ft Pointer: 360° = 1000 ft							
2. Drum for Thousands Pointer: 10 Units X 100 ft	X			X			
3. Radar-Green Over Str. Vertical Tape			X		X		
4. 3-Pointer 10000, 1000, 100		X					
5. 2-Pointer Flt Inside Cabin							X
6. Vertical Tape Flt on Left, Cabin-R							
7. Drum-Pointer Flt Drum Inside Cabin Pointer							
8. Command Altitude 5 Digit Counter							
9. Command Altitude 3 Digit Counter Plus Fix 00						X	

Legend

P - Primary
BU - Backup
R - Radar

engine location. As with speed indicators, the question of powerplant function indications should be referred to industry for discussion of possible future standardization.

Closely related to powerplant output indications are ignition and start systems and fire extinguishing systems. For starting, there are rotary switches, guarded toggles, and recessed push-buttons; and for fire, there are both manual sequences and automatic handles that incorporate the idle, shutoff, and bottle discharge actions. No great weight was placed on a need for further standardization in these areas. Illustrations of vertical tape and round dial powerplant instrumentation are shown in figure 6.

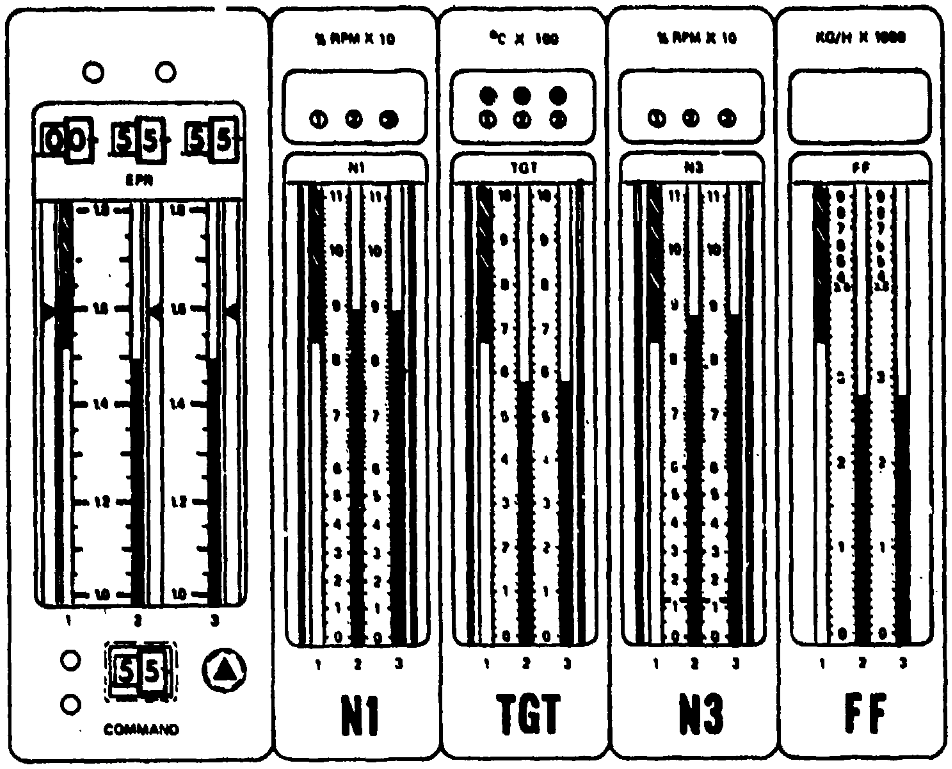
The general point most often made about electric power and hydraulic power system controls and displays was that all of them should be configured like the L-1011. The configuration of this recent aircraft facilitates understanding of flow relations and aids in carrying out corrective checklists. The panels are layed out as system outlines or diagrams (figure 7).

Because of the complexity of these systems and the complicated reversion sequences that are necessitated by engine loss or certain other casualties, electric and hydraulic systems are principal candidates for increased automation. An example is found in the latest two-man transport aircraft where substantial simplification has been achieved. It is believed that progress is being made along both these fronts, redrawing the panels to aid understanding of flow relations and automation simplification. No additional or different emphasis is necessary at this time.

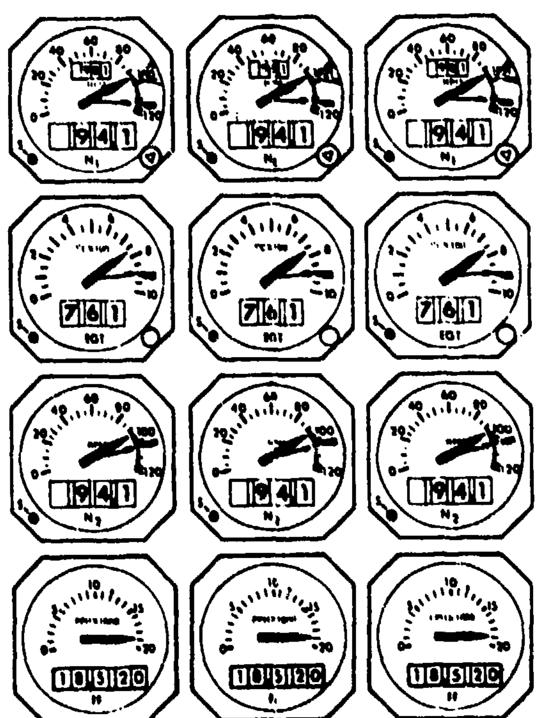
As indicated in the initial discussion, an examination of aircraft flight deck interface metrification was made. As is well known, the metric system does not have a convenient unit of length between the centimeter and the meter for expression of altitude. One-thousand-foot and two-thousand-foot vertical separations have proved effective for safety, and these do not convert conveniently to metric terms in round numbers. Hence, altimeters all over the world are calibrated in feet and thousands of feet or flight levels. The International Civil Aviation Organization (ICAO) has studied possibilities for altitude metrification, but no absolute timetable has been agreed upon.

Certain other quantities are neither metric nor nonmetric: e.g., direction in degrees, IAS, Mach, trim and flaps in degrees, time, and speed of revolutions (percent or revolutions per minute). For all of these, there seems to be no marked variation or conflict. Also, the question of metrification has been rendered moot in those cases when it was not necessary to specify a unit; e.g., hydraulic fluid levels are often indicated simply as fractions between "empty" and "full," engine bleed control systems may be indexed with only the word "cooler" and an arrow to show the cool-warm directions, and pressure control doors may show simply an "open" direction and a green operating arc.

In remaining areas, particularly air temperatures, pressure indications, weights, altimeter settings, distance measuring equipment (DME) and director distance, and range rings on weather radar or other navigation displays, this inquiry found nonstandardization and the occurrence of mixed systems. In examining panel layouts of aircraft built in the U.S. and in continental metric-standard areas, we found general agreement on certain such mixed systems and national variations on others. Non-U.S. aircraft often use pounds per square inch (psi) for pressure readings, surprisingly enough, since kilograms have become common for fuel-flow and systems panel displays in the U.S. A more predictable finding is that all



VERTICAL TAPE



ROUND DIAL

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FIGURE 6. VERTICAL TAPE AND ROUND DIAL POWERPLANT INSTRUMENTS

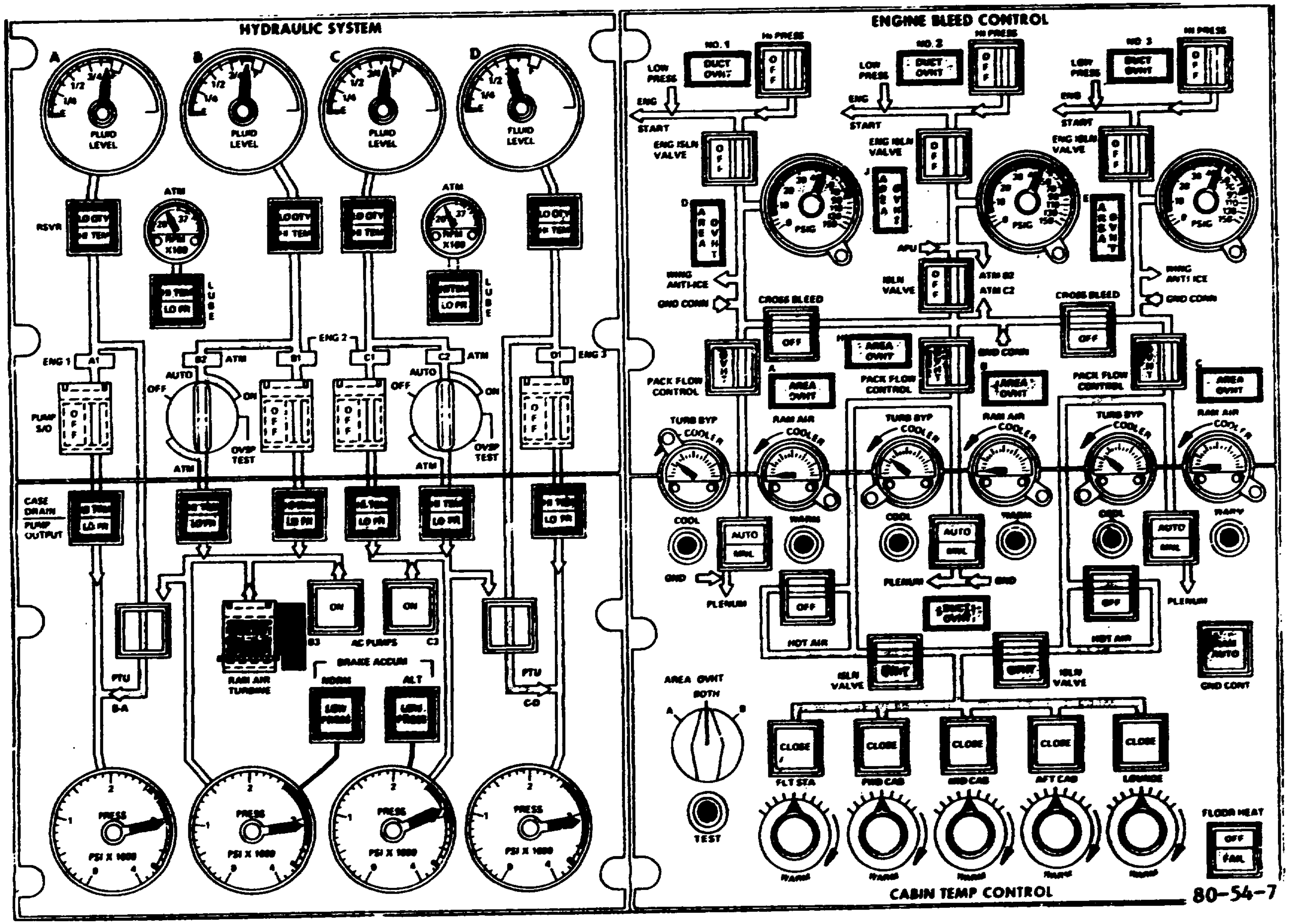

FIGURE 7. L-1011 SYSTEMS DIAGRAMS ON THE SECOND OFFICER'S PANEL

temperatures in French-built A-300's are centigrade; but many recent U.S.-built aircraft use centigrade for engine and oil temperatures and even for cargo and environmental control system temperatures, but revert to Fahrenheit for cabin temperature, apparently to facilitate communication with the cabin occupants.

We have found, then, that there is only partial acceptance of metrification in flight deck interfaces, and that finding applies to European aircraft as well as to those manufactured for use in the U.S. We believe that the trend is toward metric standardization in all those areas where metric is different from the English system with the exception of altitude. Just as building panels are 4 by 8 feet in size although expressed in metric equivalents in most metric-standard nations, certain physical relations in the real world are convenient to express in feet. The metric system needs an equivalent unit, larger than a centimeter and smaller than a meter. Unless such a unit can be made conventional, and the obstacles appear formidable, the foot may survive in altimetry. The present survival of psi in Europe may suggest that the metric system has an equivalent weakness in the wide spread between grams or kilograms per centimeter squared and kilograms per square meter. Pressure indications appear, however, to be more suitable to the "no-unit" coding approach, whereby zero and a maximum, a green normal operating range, an amber transition zone, and a redline are superimposed on index marks which have no stated numerical values.

In view of the close attention being paid to metric problems by ICAO and the evident lack of problems in selling aircraft across oceans, no near-term action on metrification is proposed.

PROBLEM AREAS

THE GENERAL PROBLEM OF STANDARDS.

It is well-established that the effectiveness of human cognitive functions such as perceiving, thinking, and decisionmaking can be highly dependent on the "quality" of the information provided. Insofar as the aircraft pilot receives important information from specially designed synthetic displays or instruments, his effectiveness in correctly understanding the situation, conceptualizing the demands for action, and following his progress in nulling-out errors will be affected by the quality of the instrument indications.

The effectiveness of information provided to pilots can be increased by adherence to the usual dictates of human engineering. For example, presentations must be unambiguous, information should be winnowed so that only that which is relevant is presented in the primary area of attention, items requiring different actions should be presented in clearly different forms, information requiring collation or comparison should be available simultaneously and alongside, and presentations should be standardized.

In the past, efforts to encourage standardization have erred in two opposing directions. Often, instrument layout standards and performance standards have been "motherhood" statements saying that all important data must be visible and that pilots must be able to perform all important functions without difficulty. Such rules are no rules at all because it is left up to the examiner to determine his own interpretation of correct operation and reasonable effort. The opposite error has been made in mandating installation of a particular device that was thought to be a solution to a problem, but which sometimes seems to create a new problem by itself (an example of the latter has been alleged in the case of the Ground Proximity Warning System).

To avoid the overly general statements, the best engineering practice should be summarized in the form of detailed requirements for both the performance of critical instruments, such as attitude displays, and for flight deck layouts. This can be done in such a way that there is more standardization on what is known to be required, what is known to be best, and what is standard and familiar where there are many alternatives of apparently equal merit. Attention to future developments will avoid hampering progress. All such detailed requirements could, for example, contain a "new technology" clause providing for specification of the type and amount of evidence that will be required to show that a new technique should be approved.

An example of the level of detail thought to be appropriate to such a specific flight deck design standard may be cited in the matter of warning systems. We know now that (1) there should be a central warning panel, not widely dispersed alarms, (2) there should be no more than five or six different audible warnings that are expected to be discriminated by general class of sound, and (3) tactile warning should probably be reserved for stall imminence. Such a standardization statement would be much more useful than one that merely required warnings to be commanding and different.

DUAL QUALIFICATION AND POSSIBLE HABIT INTERFERENCE.

On the first trip taken to obtain data for this project, the DC-10 captain operating the flight informed us that he regularly flys 707's but was moved up to this DC-10 flight due to absenses of more senior captains. He met the FAA requirement for DC-10 qualification, but he had flown only 707's during the preceeding 4 weeks. One aspect of this investigation was an inquiry as to the incidence of dual qualification and mixing aircraft types within the schedule of a given pilot. This question is considered important because airlines have been much less successful in standardizing flight deck interfaces across aircraft types in their fleets than they have been within a single type. There are no known instances of reversed control actuations, such as have been observed in railroad locomotives of different manufacturers, but it is known that radically different control forces are required to affect attitude changes in some of the earlier turbojects; e.g., 707 versus the DC-10 and later designed aircraft. Because of the differences in handling avionics, flight directors, flap setting procedures, and the like, it is considered undesirable for a pilot to fly one type most of the time but occasionally fill-in for another type. Under stress, there is a small probability of habit interference.

Examination of the pilot bid sheets obtained from two domestic trunk airlines showed that all monthly blocks of flights are in one type. This does not rule out, however, a pilot bidding relief on a type different from his usual assignment. Pilot status report sheets revealed that 16 percent of the captains, 18 percent of the first officers, and 17 percent of the second officers held multiple equipment qualifications. Much smaller percentages of the pilots held current qualifications in different seats in multiple equipment (1, 9, and 3 percent).

There is an irreducible incidence of situations in which a pilot must change from one type equipment to another or from a higher ranking seat in one aircraft to a lower ranking seat in a premium aircraft. These instances follow upon transition training, the needs of training department and other management pilots to reexperience line operating conditions, and from seasonal variations in demands for charter schedules, cargo flights, and other variations. Because of these factors, there will always be some pilots flying who have more experience in other seats. We believe that the incidence of this situation is less than 10 percent; however, considering the median crew of three pilots, any one of whom may have recently changed seats, the overall incidence of flying in different aircraft may be higher when viewed by crew rather than by individual pilot. Table 2 shows an example of multiple qualifications with one airline management group.

We know of one certificated air route carrier that publicly states that no dual qualification is allowed. Apparently, the least senior pilots qualified for upgrade seats are barred from falling back to the earlier positions, as allowed by other airlines, on those months when seniority is not sufficient to command a bid selection in the higher paid seats.

In discussions with pilots, the question of dual qualification was not reported to be a major problem, although training people state that increased standardization across types would be desirable. According to our sample of opinions, it is more important to be current on the route being flown than it is to have had exclusive experience in past months on the present type of equipment. Qualification films are said to be a poor substitute for actual airport familiarity.

At two airlines, we were assured that when management pilots made their occasional trips to maintain captain's qualifications, they drafted route-qualified captains to fly as first officers as a matter of company policy. Due to the importance of approach planning and the various properties of approach plates and other aids, this practice appears to be reasonable.

TABLE 2. MULTIPLE QUALIFICATIONS OF ONE AIRLINE'S FLIGHT TEST ENGINEERING PILOTS

B-737	B-727	DC-8	DC-10	B-747
X	X	X	X	X
X	Ⓧ	X	Ⓧ	X
X	Ⓧ	Ⓧ	X	X
X	Ⓧ	X	Ⓧ	X
X	X	Ⓧ	X	Ⓧ

X Captain/First Officer
◯ Flight Engineer

CONCLUSIONS AND RECOMMENDATIONS

There is a consensus among key personnel of transport aircraft manufacturers and airlines that there is a need for more flight deck standardization in the man-machine interfaces of flight critical systems. The problem of preserving the present degree of standarization and extending it where needed is particularly acute, due to the development of electronic instruments that are generated by computer graphic techniques under software control. Airworthiness standards with the force of law should be written in sufficient detail to constrain applications to the best known engineering practice but should not mandate particular devices and ways of attaining required performance levels. Industry committees such as those sponsored by the Society of Automotive Engineers (SAE), Air Transport Association (ATA), and Aeronautical Radio, Incorporated (ARINC) should have full Federal Aviation Administration (FAA) participation with qualified technical personnel representing the government. The "voluntary" standards resulting from actions of these industry-government groups should be relied upon to extend the level of detail more nearly to specific designs and specifications.

The flight critical areas most in need of near-term attention for increased standardization are: primary flight guidance instrumentation, particularly the Electronic Flight Instrument System (EFIS); altimeters, particularly elimination of three-pointer displays and encouragement for all-digital readouts; and improvement in design and standardization of pilot input keyboards, readouts for verification, and mode selectors. Additional areas for industry consultation, possibly leading toward standardization at some future date, were proposed as including: flap, slat, and leading-edge device control and display systems; indicated airspeed (IAS)-Mach indicators; powerplant instrumentation; and electric power and hydraulic power diagrams, displays, and controls.

Examination of progress in metric standardization revealed a surprising persistence of a mixed system of units, including altitude in feet and pressures in psi in Europe, and various uses of metric and English units for weight and temperature in the United States. No special action seems required in this field at the present time.

The incidence of dual pilot qualifications as found in two airlines studied suggest that as many as 20 percent of airline flights may be operated with one or more flight crewmembers whose recent experience has not been in that cockpit. The full significance of this is not obvious; further study should be initiated.

Probably the single most important result of this investigation is the highlighting of the forthcoming problem of certification of software controlled flight deck systems. Within the FAA there is little experience upon which to rely in this new and highly technical field. If the FAA is to interact constructively with the industry to ensure future standization, it will be necessary to increase the emphasis placed on experimental work and industry liaison. In this way, the FAA can ensure that its technical personnel have the competence to deal with the new issues that are expected to be raised.